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ORIGINAL ARTICLE

Interventional neurophysiology of the sacral nervous system

David B. Vodušek*

Division of neurology, University Medical Centre, Zaloška cesta 7, 1525 Ljubljana, Slovenia

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Summary – Clinical neurophysiological tests have been introduced for the sacral neuromuscular system to aid with diagnosis of neurogenic conditions involving the lower urinary tract, anorectal and sexual dysfunction. The tests have, however, the potential to be of value in different interventions outside of the neurophysiological laboratory. EMG monitoring can be used for exact application of botulinum toxin by the relatively non-invasive transcutaneous approach in treatment of male detrusor sphincter dyssynergia. Checking for compound muscle action potentials of the external anal sphincter is proposed as the best method for exact placement of wire electrodes close to the 3rd sacral roots in treating lower urinary tract dysfunction by 'neuromodulation'. Presently the most established use of clinical neurophysiological techniques – outside the laboratory – as related to the sacral neuromuscular system is in the operating theatre. These tests have been introduced to identify relevant structures, for instance pudendal afferents within dorsal sacral roots, which should be spared during rhizotomy procedures for treatment of spasticity. Modified techniques are used intraoperatively to monitor the integrity of the lower sacral reflex arc (the bulbocavernosus reflex) or the lower sacral afferents throughout the spinal cord (pudendal SEP). Clinical neurophysiological tests are expected to become established in several interventions involving the sacral neuromuscular system. © 2001 Éditions scientifiques et médicales Elsevier SAS

bulbocavernosus reflex / electrical stimulation / interventional neurophysiology / intraoperative monitoring / sacral roots

Résumé – Neurophysiologie interventionelle du système nerveux sacré. Les explorations cliniques neurophysiologiques ont été introduites dans le domaine du système nerveux sacré pour le diagnostic des troubles du bas appareil urinaire, du rectum et de l'anus, et des troubles sexuels, mais elles sont utilisées aussi hors du laboratoire neurophysiologique. À l'aide du *monitoring* électromyographique, l'injection de toxine botulinique pour le traitement de la disynergie du sphincter du détrusor chez l'homme peut être faite par voie trans-cutanée. Dans le traitement du dysfonctionnement du bas appareil urinaire par la neuromodulation, l'électrode peut être placée à proximité de la troisième racine sacrée grâce à l'enregistrement de la réponse motrice directe du sphincter anal externe. Les explorations neurophysiologiques sont utilisées aussi dans les salles d'opération pour aider le chirurgien dans

*Correspondence and reprints. Tel.: +386 1 543 15 01; fax: +386 1 433 91 90.
E-mail address: david.vodusek@kclj.si (D.B. Vodušek).

l'identification des structures importantes au cours d'une intervention chirurgicale, par exemple l'identification des fibres afférentes pudendales des racines dorsales sacrées, qui permet leur conservation au cours de rhizotomie effectuée en raison de spasticité. Des techniques neurophysiologiques modifiées sont utilisées aussi pour la surveillance intra-opératoire de l'integrité de l'arc reflexe sacré (l'exploration du reflexe bulbocaverneux) et de l'intégrité des fibres afférentes sacrées dans la moelle épinière (exploration des potentiels évoqués somesthésiques). Les examens neurophysiologiques promettent de devenir un instrument très utile dans un nombre des interventions sur le système nerveux sacré.

neurophysiologie interventionelle / racine sacrée / reflexe bulbocaverneux / stimulation électrique / surveillance intra-opératoire

Clinical neurophysiology has been introduced to the sacral neuromuscular system particularly with the aim of clarifying neurogenic disorders of the lower urinary tract, the anorectum and the male sexual function. Research has first been oriented towards modification of clinical neurophysiological techniques, as introduced in 'general' clinical neurophysiology (as particularly applied to limb nerves and muscles). Then these techniques have been employed to investigate the many unknown issues related to somatic muscles and their innervation in the pelvis and perineum. Concentric needle EMG, single fibre EMG, recording of various sensory, motor and reflex responses, as well as the sympathetic skin responses, were consecutively introduced to the anogenital region, and tested in different patient populations. Efforts are made to record smooth muscle electrical activity from detrusor and penis. At some point all of the introduced methods were claimed to be of usefulness in clinical diagnosis of individual patients. The recent Consensus Papers related to the investigation of patients with incontinence [19] and patients with erectile dysfunction [9] have stated, however, that only selected techniques (particularly concentric needle EMG of pelvic floor muscles, and the recording of the bulbocavernosus reflex) have established usefulness in very selected groups of patients; particularly in patients with clinically suspected lesions involving the peripheral sacral reflex arc [18] The remaining tests remain interesting research tools, and new methods are still being added to the 'sacral test battery' [2].

Furthermore, clinical neurophysiological methods have been taken out of the clinical neurophysiological laboratory to help with some particular interventions related to the sacral neuromuscular system. These applications of clinical neurophysiological methods may not yet be widely spread nor fully established. They, however, show promise in at least three particular areas: botulinum injection therapy, application of electrical stimulation devices for treatment of sacral dysfunction, and intraoperative monitoring. Therapeutic electrical and magnetic stimulation for sacral dysfunctions (urinary and faecal incontinence, micturition disturbances, and pelvic pain) are not discussed in the article.

BOTULINUM INJECTION TREATMENT

Botulinum injection treatment is routinely used for a range of extrapyramidal and spastic disorders and has also been introduced to alleviate detrusor sphincter dyssynergia. The injections into the urethral sphincter were made endoscopically [13]. The alternative adopted in our setting is botulinum injections with EMG guidance which is less invasive and less cumbersome. Treating sphincter dyssynergia in men is one of the botulinum applications in which EMG guidance seems to be important for obtaining good results, as blind transcutaneous location of the deep-seated urethral sphincter is undependable. In men, the urethral sphincter is located at the apex of prostate. With the use of a special teflon-coated injection needle with insulation removed from the tip, the EMG signal can be recorded while the needle is slowly approached to the apex of the prostate (as in the technique of EMG recording from the urethral sphincter muscle in the male). Thus, the correct position of the needle tip right at the apex of the prostate (where there is abundant on-going EMG activity) can be chosen for botulinum injection. It has to be added, however, that botulinum treatment is reserved only for a minority of patients, who decline other types of treatment; they have to be closely monitored for recurrence of dyssynergia.

ELECTRICAL STIMULATION TREATMENT

Electrical stimulation applied to the pudendal nerve and sacral roots has been demonstrated to inhibit over

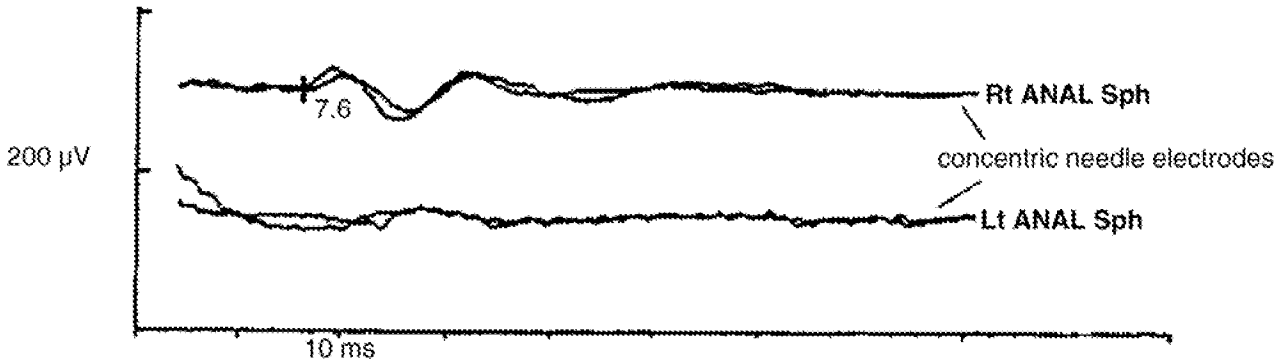

Figure 1. Intraoperative recording from left and right external anal sphincter muscle in an anaesthetized patient after the action of muscle relaxant has worn off. Intraoperative selective stimulation of the right S3 root has been performed with hand-held hook electrodes and single electrical rectangular pulses, 0.1 ms long. Two consecutive recordings are superimposed. A compound muscle action potential (CMAP) can be seen ipsilateral to the stimulation. No reflex response is seen; reflex responses can only rarely be recorded in anaesthetized subjects with single electrical pulses.

active detrusor contractions and – if applied therapeutically – help patients with urgency, frequency of micturion and urge incontinence [14]. Although therapeutic effects may be achieved with external application of electrical stimulation (vaginal, rectal, clitoral electrodes) most recent and well-controlled studies have been performed with sacral root stimulation, applying the so-called 'neuromodulation' treatment [InterStim, by Medtronic]. The technique requires introducing wire electrodes close to the sacral roots (more roots may be tested, but usually the unilateral S3 root stimulation has been chosen so far). The good positioning of the stimulation electrode is crucial for obtaining results, and is checked by the application of electrical stimuli while introducing the electrode. The standard checking is made by visual observation of pelvic floor muscle (anal sphincter) contraction. A more accurate way of establishing close contact of the stimulating electrode to the S3 root as suggested by Rick Smith [19] is to check the anal sphincter compound muscle action potential (CMAP). Although it was claimed in a recent publication [Fowler et al. 1999] that only reflex muscle responses could be obtained from the anal sphincter during S3 root stimulation, it turns out the recordings had been made contralaterally to the stimulated root [Fowler, personal communication].

It can be argued that unilateral S3 stimulation certainly is expected to elicit ipsilateral direct external anal sphincter muscle responses (i.e. CMAP/MEP) as well as ipsi- and contralateral reflex responses. But reflex responses in the perineal muscles can be easily obtained by stimulating practically anywhere in the lumbosacral region [17], and the reflex responses per se are most probably not a very good indicator of electrode closeness to the S3 root. It is true that physiological experiments indicate that the important fibres to be depolarized to achieve therapeutic results are the S3 afferent fibres (and not the S3 motor fibres), but this is a different issue.

Because the reflex responses are 'specific' neither for the S3 root, nor probably for electrode 'proximity' to root, only sphincter CMAP obtained on stimulation with very low amplitude stimuli can be taken as an indicator (or proof) of a good electrode position. In contrast to what seemed to be suggested by previous authors [Fowler et al. 1999], unilateral anal sphincter CMAP certainly can be obtained by selective intraoperative electrical stimulation of root S3 *(figure 1)*.

At present, most authors applying 'neuromodulation' do not use neurophysiological recordings. But it makes good sense that for such sophisticated therapy a more sophisticated control of electrode placement would be desirable. Further research will clarify the relevance of electrophysiological recordings during the interventions related to therapeutic electrostimulation.

INTRAOPERATIVE MONITORING

Clinical neurophysiological techniques have been demonstrated to be useful in the surgical theatre for two different purposes: for intraoperative identification of relevant neural structures, and for (continuous) monitoring of functional integrity of particular neural structures during surgery.

Intraoperative identification of pudendal afferents in sacral roots

Identification of relevant sacral structures by neurophysiological techniques intraoperatively started with EMG recordings from the anal sphincter in patients with spinal dysraphism, in whom unidentified structures were electrically stimulated and – if inducing response in the anal sphincter – preserved. Thus it was reported that such use of neurophysiologic techniques allowed spinal operations in 10 patients without changes in their neurological or urological function [6]. 'Nerve sparing' modifications trying to preserve nerve bundles were introduced into various pelvic surgeries thus preserving innervation of pelvic floor organs and their function. These interventions should be significantly improved by the recent advances in intraoperative identification of cavernosal nerves by electrical stimulation, and recordings made from corpora cavernosa [11, 15].

In another application, sacral intraoperative neurophysiology has already established value. During the past decade, increasing numbers of neurosurgeons have included sacral roots in the rhizotomy procedure for treatment of spasticity. S1 roots have always been a potential target for rhizotomy, but the S2 dorsal roots have been mostly excluded from the procedure for fear of inducing lower urinary tract and sexual dysfunction. Sparing the S2 roots from rhizotomy, however, may allow the 'remaining' abnormal reflexive circuits to cause spasticity in the musculature of the lower extremities. Thus it has been demonstrated that children who underwent L2-S2 rhizotomies had an 81% greater reduction in plantar flexors spasticity compared to children who underwent only S2-S1 rhizotomies [8]. As more sacral roots are included in rhizotomies, the potential risk for postoperative complications related to sacral dysfunction, however, increases. The reported incidence of bladder dysfunction after selective dorsal rhizotomies may be up to 24%, and there seems to be a tendency among neurosurgeons to underreport the occurrence of such complications [10]. Because the median age of patients undergoing rhizotomy is typically between 3 and 4 years, not all symptoms are effectively communicated. Possible (consecutive) sexual complications cannot be evaluated at all. Techniques that protect afferent fibres from the anogenital region and the pelvic organs should decrease complications of rhizotomies. As direct electrical stimulation of bladder and bowel afferents is technically difficult, stimulation of the cutaneous branches of the pudendal nerve was proposed as a practical alternative. Furthermore, preserved sensation of genitals is paramount to normal sexual response and is relevant for normal sexual development. After such considerations, intraoperative pudendal afferent mapping of the sacral roots was successfully introduced [4]. The recordings were made intraoperatively from the dorsal roots which were differentiated from the ventral roots by the anatomic position and their characteristic appearance. The dorsal penile or clitoral nerves were electrically stimulated by surface electrodes and the dorsal root action potentials were directly recorded from the S1-S3 dorsal roots using a hand-held hook electrode *(figure 2)*. If any sensory action potential was recorded on a 'pathological' root (as subsequently determined during the afferent root/rootlet stimulation used to direct the dorsal rhizotomies), the root was subdivided and the action potentials on each rootlet were tested again. The rootlets with significant pudendal afferent activity were spared from rhizotomy [4]. A further report on 114 children with debilitating spastic cerebral palsy revealed successful afferent mapping performed in 105 children undergoing selective dorsal rhizotomies. Although some contribution of pudendal afferent activity was frequently recorded from S1 roots it was never the major component. On the contrary, S2 roots carried more than 2/3 of pudendal afferent fibres in 50% of the patients. Overall 32% of the S2 rootlets were cut in children who underwent pudendal nerve mapping, as opposed to 65% being cut in children who were operated on before the introduction of this technique. Five per cent of the patients had difficulty voiding during the immediate postoperative period, mostly complaining of disuria (suggesting urethritis presumably associated with catheterisation). All of the children began voiding spontaneously within 1 to 2 weeks after surgery. Thus none of the 105 patients who underwent successful sacral root mapping developed long-term bowel or bladder complications [5]. This compares favourably to the 24% incidence of transient bladder dysfunction with one patient left with permanent disability requiring intermittent catheterisation in children operated before introduction of the mapping procedure [1]. The results also suggest that the root distribution of afferent fibres which are important for the control of voluntary micturition may be similar to the distribution of mucocutaneous afferent fibres from the pudendal nerve.

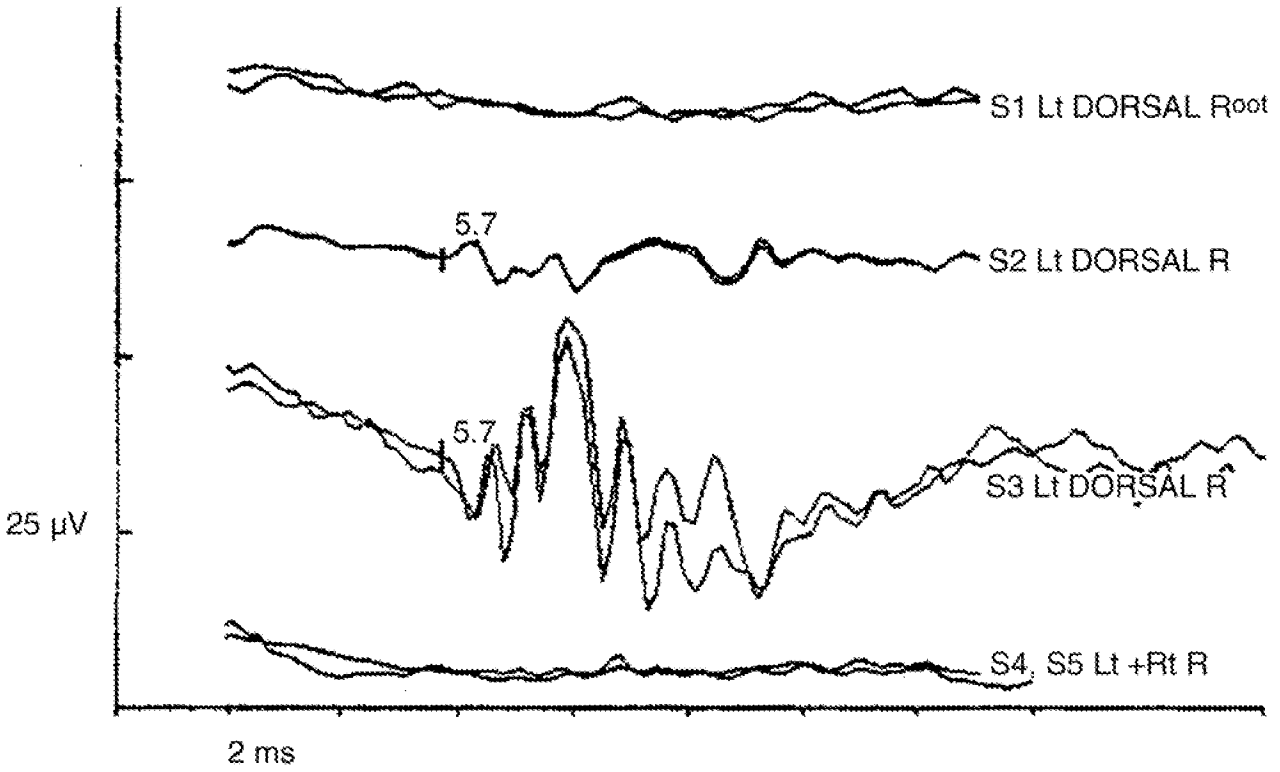

Figure 2. Intraoperative recording from dorsal sacral roots in an anaesthetized patient was obtained with hook electrodes; electrical stimulation of penis was performed with surface electrodes. The predominance of penile afferents distribution on the left to the root S3 can be seen.

Intraoperative monitoring of sacral nervous structures

There is a growing awareness that surgically induced lesions to nervous structures are avoidable with the aid of intraoperative monitoring of their functional integrity, and such monitoring is already routine in many surgical and neuroradiological procedures. The lost functional integrity of sacral nervous structures may result in disorders of micturition, defecation and sexual function. Several neurophysiological techniques have been introduced to provide intraoperative monitoring of selected sacral structures, for instance root stimulation and recording of the anal sphincter pressure, or recordings of neurotonic discharges in response to nerve irritation [7, 12]. As the bulbocavernosus reflex response is the neurophysiological parameter reflecting the integrity of the whole lower sacral reflex arc, it was chosen as a suitable technique for intraoperative monitoring the integrity of the cauda equina and conus medullaris. It was also chosen as practical because both stimulation and recording are performed outside of the surgical field. The feasibility of intraoperative recording of the BCR response was demonstrated in a group of 119 patients, both adults and children, both males and females [4]. For stimulation, surface electrodes were applied to the penis and clitoris and paired electrical stimuli were used. The optimal interstimulus interval was found to be 3 ms and the optimal stimulating rate 2.3 Hz. Further experience demonstrated that a train of 4 pulses was even better to obtain reproducible reflex responses in the regime of anaesthesia with propophol, phentanyl, and nitrous oxide. Of course only a short acting relaxant can be used during surgeries requiring such monitoring. Recordings were made from the anal sphincter (from the right and left half separately) using intramuscular wire electrodes *(figure 3)*. The technique requires at least some preoperative preservation of the lower sacral reflex arc. It is technically easily applicable in males, but has still some technical problems related to less satisfactory stimulation technique in females [16]. It has so far been applied in more than 100

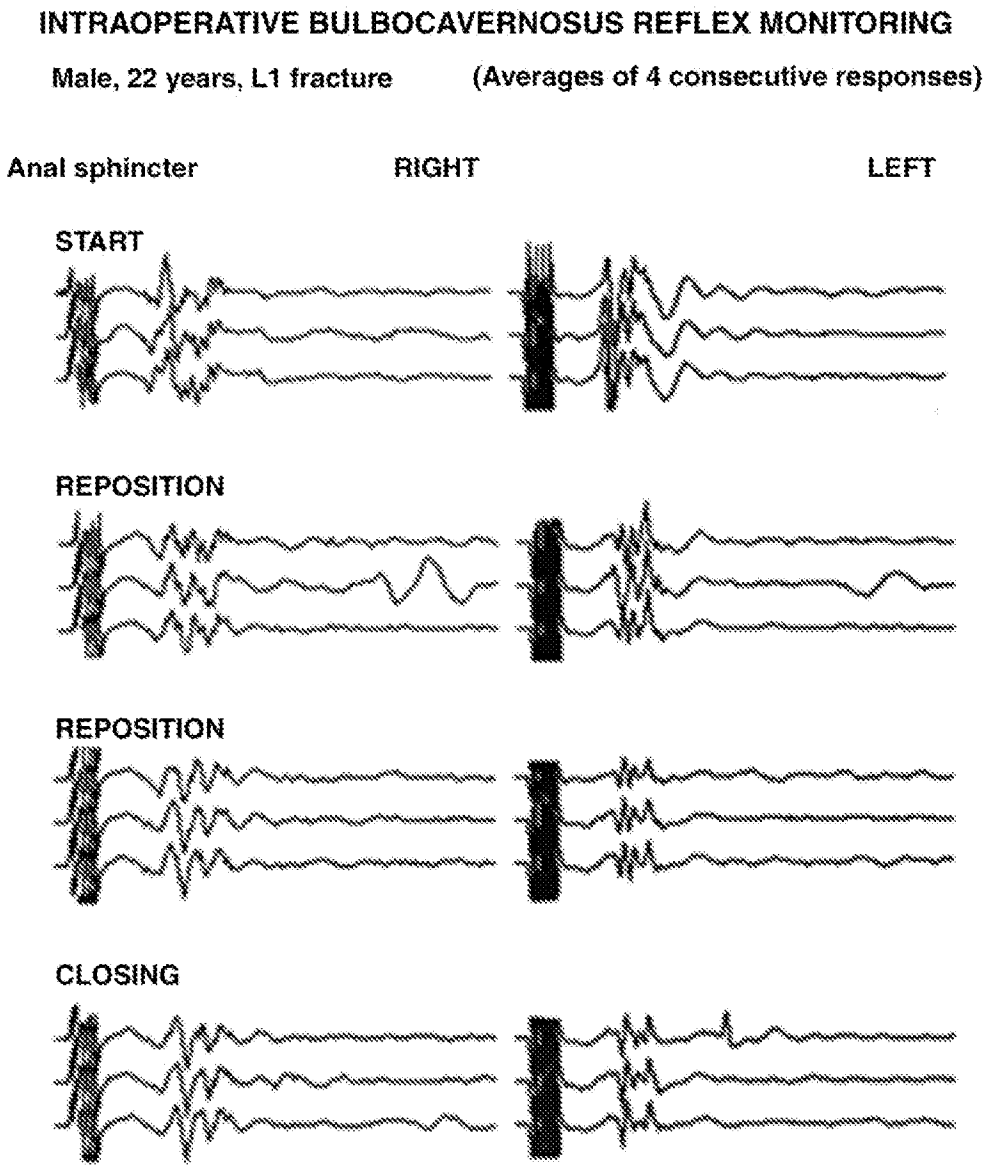

Figure 3. Intraoperative recording of the bulbocavernosus reflex in a male after traumatic L1 fracture, without neurological deficit. Responses were recorded from external anal sphincter (bilaterally) with wire electrodes, on electrical stimulation of penis with surface electrodes. Trains of four pulses were applied at 2.3 Hz, every four consecutive responses averaged. Prolonged intervals of monitoring were performed during crucial periods of surgery, during which bone fragments were removed from the spinal canal. No significant change in the response was seen, and the patient remained without deficit after surgery.

patients at risk for conus or cauda equina damage, with no false positive or false negative results so far.

Pudendal somatosensory evoked potentials is another method which has been introduced to intraoperative monitoring, and shown to be easily applicable also under the regime of anaesthesia [3, 20]. It was suggested as useful in procedures involving the spine or spinal canal below the S1 level. A large series of 154 patients revealed one case of a false positive response, and no false negative response [3]. Technically more difficult is the recording of spinal cord evoked potentials on stimulation of lower sacral afferents *(figure 4)*,

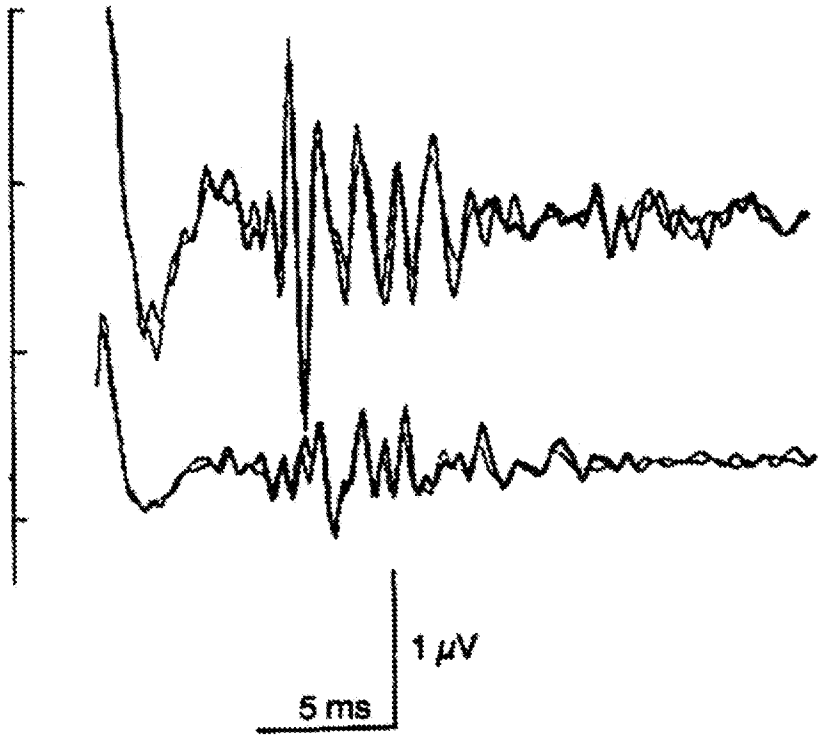

Figure 4. Intraoperative recording of (spinal) somatosensory evoked potential at L1/2 (upper beam) and Th1 (lower beam) with epidural electrodes, on electrical penile stimulation. (Rectangular pulses, 0.1 ms, at 13.3 Hz; two consecutive series of 100 responses averaged and superimposed).

which has not yet been employed for monitoring purposes in more than a few patients.

CONCLUSION

Clinical electrophysiological methods as applied to the sacral neuromuscular system are used as research tools; several test are used in the clinical neurophysiological laboratory to refine the diagnosis of a neurogenic lesion involving the lower sacral segments. The versatility of the tests makes them also perfect candidates for interventions in the sacral region, particularly for identification of structures, and intraoperative monitoring of the integrity of nervous system. Further developments are expected, as the awareness of the significance of sacral neurocontrol is increasing.

REFERENCES

1 Abbott R. Complications with selective posterior rhizotomy. Pediatr Neurosurg 1992 ; 18 : 43-7.

2 Amarenco G, Kerdraon J. Pudendal nerve terminal sensitive latency: technique and normal values. J Urol 1999 ; 161 : 103-6.

3 Cohen BA, Major MR, Huizenga BA. Pudnedal nerve evoked potential monitoring in procedures involving low sacral fixation. Spine 1991 ; 16 (Suppl.) : 375-8.

4 Deletis V, Vodusek DB. Intraoperative recording of the bulbocavernosus reflex. Neurosurgery 1997 ; 40 : 88-93.

5 Huang JC, Deletis V, Vodušek DB, Abbott R. Preservation of pudendal afferents in sacral rhizotomies. Neurosurgery 1997 ; 41 : 411-5.

6 James HE, Mulcahy JJ, Walsh JW, Kaplan GW. Use of anal sphincter electromyography during operations on the conus medullaris and sacral nerve roots. Neurosurgery 1979 ; 4 : 521-3.

7 Kothbauer K, Schmid UD, Seiler RW, Eisner W. Intraoperative motor and sensory monitoring of the cauda equina. Neurosurgery 1994 ; 34 : 702-7.

8 Lang FF, Deletis V, Cohen HW, Velasquez L, Abbott R. Inclusion of the S2 dorsal rootlets in functional posterior rhizotomy for spasticity in children with cerebral palsy. Neurosurgery 1994 ; 34 : 847-53.

9 Lundberg PO, Brackett NL, Denys P, Chartier-Kastler E, Sønksen J, Vodusek DB. Neurological disorders: Erectile and ejaculatory dysfunction. In: Jardin A, Wagner G, Khoury S, Guiliano F, Padma-Nathan H, Rosen R, Eds. Erectile dysfunction: Health Publication; 2000. p. 593-645.

10 McDonald C. Selective dorsal rhizotomy: A critical review. Phys Med Rehab Clin N Am 1991 ; 2 : 891-915.
11 Michl U, Dietz R, Huland H. Is intraoperative electrostimulation of erectile nerves possible? J Urol 1999 ; 162 : 1610-3.
12 Pang D, Casey K. Use of an anal sphincter pressure monitor during operations on the sacral spinal cord and nerve roots. Neurosurgery 1983 ; 13 : 562-8.
13 Petit H, Wiart L, Gaujard E, Le Breton F, Ferriere JM, Lagueny A, Joseph PA, Barat M. Botulinum-A toxin treatment for detrusor-sphincter dyssynergia in spinal cord disease. Spinal Cord 1998 ; 36 : 91-4.
14 Plevnik S, Vodusek DB. Electrical therapy, part one: Non-implanted. In: Stanton SL, Monga AK, Eds. Clinical Urogynaecology, second edition, chapter 43. London: Churchill Livingstone; 2000. p. 521-30.
15 Rehman J, Christ GJ, Kaynan A, Samadi D, Fleischman J. Intraoperative electrical stimulation of cavernosal nerves with monitoring of intracorporeal pressure in patients undergoing nerve sparing radical prostatectomy. B J U International 1999 ; 84 : 305-10.
16 Rodi Z, Vodusek DB. Intraoperative monitoring of bulbcavernosus reflex – the method and its problems. Clin Neurophysiol 2001 ; 112 : 879-83.
17 Vodušek DB. Evoked potential testing. Urol Clin North Amer 1996 ; 23 : 427-46.
18 Vodušek DB. Electromyogram, evoked sensory and motor potentials in neurourology. Neurophysiol Clin 1997 ; 27 : 204-10.
19 Vodušek DB, Bemelmans B, Chancellor M, Coates K, Kerrebroeck P van, Opsomer RJ, Schmidt R, Swash M. 4. Clinical Neurophysiology. In: Abrams P, Khoury S, Wein A, Eds. 1st International Consultation on Incontinence, June 28 – July 1, 1998, Monaco. Incontinence. Plymouth, U.K.: Health Publication Ltd.; 1999. p. 157-95.
20 Vodušek DB, Deletis V, Abbott R, Epstein FJ, Turndorf HH. Intraoperative monitoring of pudental nerve function. In: Rother M, Zwiener U, Eds. Quantitative EEG analysis – clinical utility and new methods. Jena: Universitätsverlag Jena; 1993. p. 309-12.